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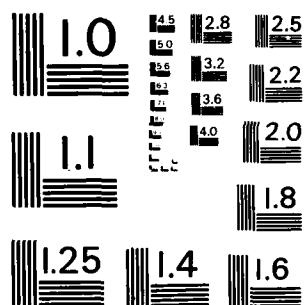   AFOSR-TR-84-0002 AFOSR-82-0249
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OPTICAL PROCESSING IN RADON SPACE

AFOSR- 82-0249

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

   The Radon transform is the mathematical basis of computed tomography.
The two-dimensional (2D) Radon transform consists of a series of 1D
projections of a 2D function, obtained by integrating the function along
lines, while the 3D Radon transform consists of 1D projections of a 3D
function, obtained by integrating over planes. In both cases, the transform
serves to reduce the dimensionality of a function from 2D or 3D to 1D. For
signal-processing applications, this dimensionality reduction is very useful

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because of the availability of sophisticated processing devices, such as SAW
and CCD filters, for 1D time signals. The Radon transform permits the use
of these devices with 2D and 3D data sets. The operations that can be
performed with the help of the Radon transform include: convolution,
correlation, Fourier analysis, bandwidth compression, space-variant
filtering, adaptive filtering, calculation of the Wigner distribution and
ambiguity function, and calculation of moments of an image. In all of
these cases, the operations can be carried out on a 2D or 3D data set by
first performing a Radon transform, then doing a sequence of 1D operations,
and finally performing an inverse Radon transform.

In the first year of this proposed three-year program, we have made
substantial progress toward the program goals. We have investigated the
application of the Radon transform to several areas of signal processing,
including space-variant operations and compression. We have constructed a
flying line scanner to derive the Radon transform of an input transparency,
and interfaced it with surface acoustic wave chirp filters to produce a 2D
spectrum analyzer. We have investigated materials suitable for data
storage via spectral hole burning. We have begun construction of a custom
surface acoustic wave filter needed to perform the inverse Radon
transform.

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Introduction

It is well-known that many mathematical operations on data sets of dimensions two or higher may be performed by reducing the data to one-dimensional projections via the Radon transform. For instance, this is the mathematical basis for medical computed tomography. The two-dimensional (2D) Radon transform consists of a series of 1D projections of a 2D function, and is produced by integrating along lines. The 3D Radon transform produces a 1D function by integrating the 3D function over planes. In signal processing applications, the reduction in dimensionality from 3D or 2D to 1D can be very useful due to the existence of very sophisticated 1D processing devices, e.g. SAW and CCD filters. Several important signal processing functions, such as convolution, correlation, Fourier analysis, bandwidth compression, calculation of image moments, Wigner distribution, and ambiguity function, can be carried out on 2D or 3D data by performing the Radon transform to reduce the dimensionality to 1D, performing the operation with the sophisticated 1D processors, and performing the inverse Radon transform to produce the new 2D or 3D data set.

This is a report of technical progress made during the first year of a proposed three-year program to investigate the applications of the Radon transform to signal processing. The stated goals of the program are:

(1) theoretical investigation of the role of the Radon transform in signal processing;

(2) construction of a practical system for 2D spectral analysis and image filtering at least at video rates;

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(3)   proof-of-principle experiments for other processing operations;

(4)   determination of the feasibility of 3D Radon processing.

In the first year, the specific research tasks were:

(1)   design and construct a flying-line scanner for extraction of the 2D Radon transform of an input transparency;

(2)   perform a 2D spectrum analysis using SAW devices.

(3)   experimentally investigate monolithic SAW convolvers;

(4)   perform the filtering operation required for the inverse Radon transform, the so-called rho-filter, with the SAW convolver if feasible. Otherwise, implement this operation digitally in order to obtain filtered data suitable for input to the back-projector to produce the inverse Radon transfer;

(5)   build and test an incoherent optical back-projector using a laboratory oscilloscope. This system will not have sufficient speed but will prove the principle of biased incoherent back projection;

(6)   carry out a conceptual system design and noise analysis for a 2D processing system;

(7)   investigate various options for 3D spectrum analysis and processing, with emphasis on optical layout and data storage problems.

Status of the Research

Progress made toward reaching the specific research goals for the first year is as follows:

(1) Construct the flying-line scanner.

The breadboard of the flying-line scanner has been constructed and is working well. We are now able to take projection data from input transparencies with resolution of the order of 0.5 mm. This resolution is

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limited by the speed of response of the detector amplifier and by the width of the scanning line. Although improvement in the resolution of the flying line scanner is desirable and possible, at present SAW filters used in the spectrum analyzer are the limiting factor in the system. Other improvements are to be implemented in the flying line scanner, including motorized rotation for better data collection, and the addition of a beam-splitter to allow use of the system for scanning real scenes.

(2) Perform a 2D Spectral Analysis with 1D Filters.

A set of 3 SAW chirp filters was purchased from Andersen Labs to construct a Fourier transformer and spectrum analyzer. By using 2 filters, a spectrum analyzer was constructed which, when interfaced to the flying-line scanner and a suitable display device, allows us to produce the 2D spectrum of an input scene. A schematic of the setup is shown in Fig 1. The output of the flying-line scanner is mixed with the impulse response of one of the SAW chirp filters and then convolved with the response of the second chirp filter. This output contains the Fourier transform magnitude information as an amplitude modulation on an RF carrier. By detecting the signal, the modulus of the Fourier transform of one projection of the input scene is produced. The central slice theorem shows that this is equivalent to one line through the origin of the 2D Fourier transform magnitude of the input scene. By rotating the direction of scan across the transparency, the Fourier transform modulus at any angle can be found. We are able to build up the 2D transform by applying the 1D data to the z-axis of an oscilloscope, and integrating on a film which rotates at the same rate as the angle of scan. Results from this operation are shown in Fig. 2. To produce the complex Fourier transform, the third SAW chirp filter must be used as a coherent demodulator. Precise timing of the impulse to the post-
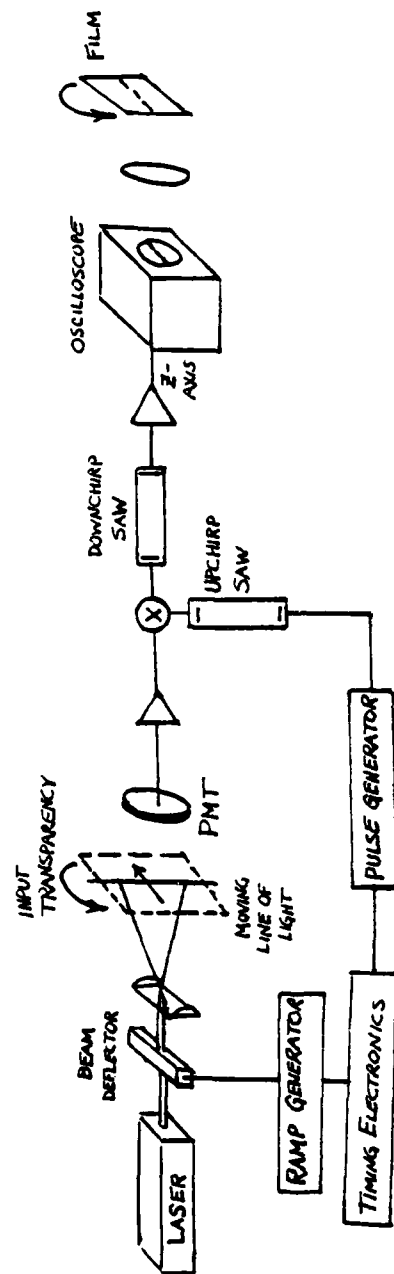
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Figure 1. Schematic of 2D Spectrum Analyzer using 1D Surface Acoustic Wave Chirp Filters

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B

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Figure 2. Result of 2D Spectral Analysis using 1D SAW Chirp Filters
via the Radon Transform. (A) Input Transparency, (B) 2D Spectrum
The resolution in the 2D spectrum is limited by the Time-
Bandwidth Product of the chirp filters

multiply chirp is required. To aid in achieving this, a Berkeley Nucleonics digital delay generator has been purchased. It recently arrived, and is presently being integrated into the system.

We have also acquired and tested a set of CCD chirp filters from Reticon Corp. These are much slower than the SAW filters, but they are more precise. We have successfully demonstrated computation of the magnitude of the Fourier transfer with them, and plan to use them in an experiment on correlation tracking of projection data shortly.

(3) Investigate monolithic SAW convolvers.

We borrowed a monolithic SAW convolver from Dr. Paul Carr of Rome Air Development Center, Hanscom Air Force Base. This device, manufactured by Andersen Labs, appears to have only about 30 dB of dynamic range when used to autoconvolve a double pulse signal (Fig. 3). This will limit its usefulness for our purposes. Nevertheless, we are currently constructing a fast programmable digital memory and digital-to-analog converter to generate the filter function required for the 2D universe Radon transform. By applying this filter function to one input of the convolver and applying the projection data obtained from the flying line scanner to the other input, the properly filtered data will be generated for the incoherent back projector (item 5). This work is well underway and should be completed within a month.

(4) Perform the filtering operation required for the inverse Radon transfer.

We plan to try two methods of filtering: using the SAW convolver as detailed in item 3, and using a custom-designed SAW filter. After investigating the possibility of having the filter manufactured commercially, price considerations led us to try to build the filter
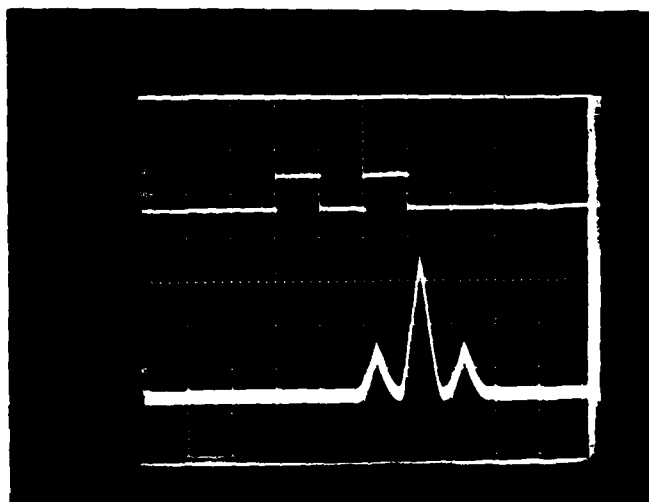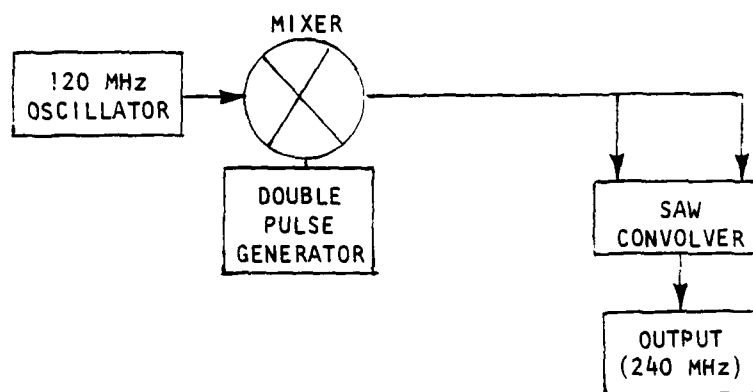
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Fig. 3. (Top) Test circuit for SAW convolver.
(Bottom) Upper trace: double pulse input. Lower trace:
envelope of convolution output; 0.5 V/division; 0.2 V/division.

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ourselves. The Microelectronics Laboratory at the University of Arizona is well equipped to handle such a task. We are presently completing work on an engineering test filter of very simple impulse response. This test device is nearly completed, and if it functions as expected, we plan to start constructing the actual filter very soon.

(5) Incoherent Back Projector

To produce the 2D Fourier transform modulus from the 1D projection (item 2), a version of the incoherent optical back projector was constructed. In this device, the transformed projection data was applied to the z-axis modulation input of an oscilloscope. By rotating a camera focused on the scope, the proper orientation of the projection data can be produced. An improved version is planned where the image will rotate on the film rather than vice versa. This is to be tried in two ways: using a dove prism to rotate the image or by rotating the scope trace electronically on the CRT. For optical back-projection, a cylindrical lens is required to smear the oscilloscope trace perpendicular to its scan direction. All optics required are on hand.

(6) Design and Noise Analysis

The basic system design concept has been formulated. The noise analysis, especially the contributions of each individual system component, is underway and will continue.

(7) 3D Processing

One of the key problems in 3D processing is data storage. A 512 x 512 point, 8 bit array takes up 0.25 Mbyte of memory, but a 512 x 512 x 512, 8 bit array will fill 134 Mbytes. We are investigating new techniques for data storage via spectral hole burning. The experiments must be done at low temperature, and so we have procured a liquid helium dewar to hold the

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samples. We are presently trying to refurbish the dewar to make it operational. We have conducted experiments in hole-burning with the cooperation of Dr. Gary Bjorklund of IBM Research Laboratories in San Jose. A candidate material for the spectral hole burning experiments has been tested. This is a sodium fluoride compound lightly doped with OH ions. The material is very sensitive (incident intensities in the nanowatt per square centimeter range are sufficient to burn holes). More importantly for our purpose, the material shows no evidence of self-erasure. In addition, the material is sensitive at a laser diode wavelength (889 nm, $GaA_\ell As$ laser). Because of some undersirable characteristics of sodium fluoride, experiments are planned to study the suitability of lithium fluoride.

In addition to the tasks in the work statement, we have completed a study of the application of the Radon transform to data compression. Good images were reconstructed after compressing the data from 8 bits/pixel to 0.7 bit/pixel in a digital simulation.

List of Personnel

H.H. Barrett, Principal Investigator, Optical Sciences Center and Department of Radiology, University of Arizona.

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Paul Atcheson, Graduate Research Associate.

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Publications Resulting from AFOSR Support:

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H.H. Barrett and and J. Walkup, "Space-variant operations in Radon space," in preparation.

Other publications describing previous work related to this grant:

A.F. Gmitro, G.R. Gindi, H.H. Barrett, and R.L. Easton, "Two-dimensional image processing by one-dimensional filtering of projection data," Proc. SPIE 388, January 1983, to be published.

H.H. Barrett, "Optical processing in Radon Space," Opt. Lett. 7, 248-250, 1982.

H.H. Barrett, "The Radon transform and its applications," to be published in Progress in Optics.

Papers Presented

R.L. Easton, Jr., H.H. Barrett, and A.J. Ticknor, Using SAW Filters to Process Two-Two-Dimensional Data via the Radon Transform," to be presented at the 1983 IEEE Symposium on Ultrasonics.

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